American Journal of Engineering Research (AJER)
E-ISSN: 2320-0847 p-ISSN: 2320-0936
Volume-7, Issue-12, pp-245-250
www.ajer.org
Research Paper Open Access

Empirical Modelling of Injection Moulded High Density Polyethylene-Grass Composite

D.D Olodu[1*] and J.O. Osarenmwinda[2]
[1, 2]*Department of Production Engineering, Faculty of Engineering, University of Benin, PMB 1154, Benin City, Edo State, Nigeria*
Corresponding Author: D.D Olodu

ABSTRACT: *Most manufacturing processes of injection moulded plastic-grass composite products have been by trial and error due to inadequate model for predicting its mechanical properties. This study was carried out to develop empirical models for predicting the mechanical properties (tensile strength, proof stress, percentage elongation and flexural strength) of injection moulded High Density Polyethylene-Grass composite. The mechanical properties of the produced High Density Polyethylene-grass composite which was obtained from the experimental study were used to develop the empirical models for tensile strength, proof stress, percentage elongation and flexural strength. The developed models were validated using coefficient of determination (R^2) and mean absolute percentage error (MAPE). The coefficient of determination obtained ranged from 0.9213 (92.13%) to 0.9911 (99.11%) which indicates that a substantial good fit was achieved by the model developed. The mean absolute percentage error of the developed models ranged from 0.12% to 6.53% which was below 10% recommended. The values obtained from the validation of these models were therefore found to be satisfactory, and shows good predictability of the model.*

KEY WORDS: *Composites, Empirical model, High Density Polyethylene, Injection moulding, Mechanical properties,*

Date of Submission: 01-12-2018 Date of Acceptance: 31-12-2018

I. INTRODUCTION

The deformable state achieved by plastic-grass composites at elevated temperature before chemically setting, allow them to be shaped to any intricate form. Injection moulding is a very complex process and its process variable like barrel temperature, injection pressure, the material flow rate, mould temperature and flow pattern usually influence the properties of polymeric materials. A qualitative analysis of the influence of these factors in this case barrel temperature on the mechanical properties of a moulded part will be helpful in gaining better insight into the presently used processing methods[1].

Moreover, some researchers carried out some investigation on modeling of composite. Chunping *et al*[2] carried out a study aimed to model fundamental bonding characteristics and performance of wood composite. In their work, mathematical model and a computer simulation model were developed to predict the variation of inter-element (strand) contact during mat consolidation. The mathematical predictions and the computer simulations agree well with each other. Their results showed that the relationship between the inter-element contact and the mat density was highly nonlinear and was significantly affected by the wood density and the element thickness.

Osarenmwinda and Nwachukwu[3] focused *on* the development of empirical models making use of previously obtained experimental data to estimate properties of produced composite material from agro waste (sawdust and palm kernel shell). The empirical model was used to predict the properties of composite material (hardness, yield strength, ultimate tensile strength, modulus of elasticity, modulus of rupture, internal bond strength, density, thickness of swelling and water absorption) taking the inputs as percentage sawdust composition and percentage palm shell composition respectively. The empirical model was developed using "MATHMATICAL PRODUCT" software program expressing the outputs in the quadratic form. The model performances were found to be satisfactory and show good predictability.

Adeyemi and Adeyemi[4] developed empirical formulas, based on the diffusion model and the drying data (i.e moisture ratios, with drying times) of the composite from sawdust were computed and presented for various curing temperature and at different percentages of hardener resin addition. The unsteady-state diffusion coefficients and surface emission coefficients of moisture in boards were separated in one experimental period by using the method of linear regression. Then the moisture transfer processes in board were analyzed by using Finite Element Method (FEM), and the moisture absorption processes of four kinds of boards were observed experimentally. By comparing the computed results with the experimental results, it showed that the error was within 10%. Therefore, they came to the conclusion that the processes of moisture transfer in composite can be described by using FEM.

Komeil et al[5] examined the designing, modeling and manufacturing of light weight carbon nanotubes/polymer composite nanofibers for electromagnetic interference shielding application. Lightweight conductive multi-walled carbon nanotubes (MWCNTs)/polyvinyl alcohol (PVA) composite nanofibers were prepared by electrospinning process with an aim to investigate the potential of such nanofibers as an effective electromagnetic interference (EMI) shielding material. The influence of MWCNTs content, thickness, and frequency on the EMI shielding of conductive MWCNTs/PVA composite nanofiber was investigated. These experiments were designed by response surface methodology (RSM) and quadratic model was used to calculation of the responses. The predicted responses were in good agreement with the experimental results according to RSM model. The RSM analysis confirmed that MWCNTs content and thickness were the main significant variables affecting the absorption shielding effectiveness. Moreover, the sample thickness has no significant influence on the reflection shielding effectiveness. The obtained RSM results confirmed that the selected RSM model presented suitable performance for evaluating the involved variables and prediction of EMI shielding parameters.

The finite element was used in this analysis as a numerical method to predict the buckling loads and shape modes of buckling of laminated rectangular plates. In this method of analysis, four-noded type of elements is chosen. These elements are the four-noded bilinear rectangular elements of a plate. Each element has three degrees of freedom at each node[6]. Barrel temperature is the key to successful moulding because one basic requirement on an automatic injection moulding process is that the moulded parts must be produced automatically without the need for secondary finishing operations. Moreover, there are inadequate empirical models to predict mechanical properties of some process variables of plastic-grass composite. This had resulted to most failure in the manufacture of these composite. This study therefore, focuses on the empirical modelling of injection moulded high density polyethylene-grass composites.

II. MATERIALS AND METHODS

2.1 Equipment and Tools

(a) Two stage-screw plunger Injection machine. Fox and offord, 70 tons two stage-screw plunger **(b)** A toggle clamp attached to the injection end of injection moulding machine was used.

(c) The mould was made of Silicon – killed forging quality steel AISI type H140 treated to 252 –302 Brine 11. Such steel was used for moulds that require high quality parts, long production runs and is s safe to use at high clamping pressures.

(d) Monsanto Tensometer, Type 'W' Serial No. 8991 was used for tensile testing experiment.

2.2 Materials

(a) The grass used for this research work was guinea grass (*Panicum maximum*);

(b) The Plastic material used for this study was High Density Polyethylene (HDPE).

2.3 Preparation and Processing of Grass

The harvested grass was washed and soaked with dilute sodium hydroxide (NaOH) of concentration 0.10mol/dm^3 for 6 hours to ensure effective bonding between the grass and the plastic (High Density Polyethylene) materials. The grass was ground to granules using crushing machine. The grasses were first air dried in the sun and later transferred to an oven and dried at 105^{o}C. It was continuously monitored until moisture content of about 4$\pm$0.2% was obtained[7]. The ground grass was screened to a particle size of 300μm diameters using vibrating sieve machine.

2.4 Production of Composites

High Density Polyethylene (HDPE) was mixed with ground grass in the proportion of 20:80, 30:70, 40:60, 50:50, 60:40, 70:30 and 80:20 respectively. The prepared High Density Polyethylene-grass composite was blended in a cylindrical container until a homogenous mixture was obtained in the composite. The homogenous mixture of the composite was feed into the hopper of injection moulding machine and was produced at various barrel temperature ranging from 210^{o}C to 310^{o}C respectively[8].

The produced composite was evaluated for mechanical strength (tensile strength, proof stress, percentage elongation and flexural strength). In this research work, all empirical models were developed using experimental values (E) obtained from the produced composite tensile strength, proof stress, percentage elongation and flexural strength results. The empirical model was used to predict the mechanical properties of the composite material (Tensile Strength, Proof Stress, Percentage Elongation and Flexural Strength) by taking the inputs as percentage by volume of plastics (M), percentage by volume of grass (K) and barrel temperature (T).

The output was obtained through the interaction between M, K and T. A quadratic model of second order regression was obtained for the plastic-grass composites for mechanical strength (Tensile Strength, Proof Stress, Percentage Elongation, and Flexural Strength). A code was written in a MATLAB program (MATLAB software, version 7.5.0 (R2007b) to investigate the interactions of the various parameters of the developed empirical model. The empirical model was expressed in the form shown in Equation 1

$$Y=Constant+\alpha_1T+\alpha_2M+\alpha_3K+\alpha_4TM+\alpha_5TK+\alpha_6MK+\alpha_7T^2+\alpha_8M^2+\alpha_9K^2 \quad (1)$$

Where M= Percentage by volume of plastic (%);K= percentage by volume of grass (%) ; T= Temperature (^OC) ;Y= Output (Mechanical Properties); $\alpha_{1,}$ $\alpha_{2,}$ $\alpha_{3,}$ $\alpha_{4,}$ $\alpha_{5,}$ $\alpha_{6,}$ $\alpha_{7,}$ $\alpha_{8,}$ and α_9 are the coefficient of T, M, K, TM, TK, MK, T^2, M^2, and K^2 respectively

2.6 Validation of the Models Developed

The mean absolute percentage error and coefficient of determination were used to validate the model. They were determined using equation 2 and equation 3 respectively.

$$\text{Absolute percentage error}=\left|\frac{Experimental\ \ value - Predicted\ \ Value\ \ X100\%}{Experimental\ \ \ Value}\right| \quad (2)$$

$$\text{Coefficient of Determination, } R^2 = \left[1-\frac{\sum(Yi-\hat{Y})^2}{\sum(Yi-\bar{Y})^2}\right] \quad (3)$$

Where Y_i= Experimental value and $\hat{Y} = Predicted\ value$

The Assumptions made in this Model are as follows:

1. The composite was produced from high density polyethylene and guinea grass.
2. The injection pressure remained constant i.e 160kg/mm^2.
3. Guinea grass with particle size of 300μm was used.
4. All the composite production parameters were kept constant except percentage by volume of material and barrel temperature of the injection moulding machine.

III. RESULTS AND DISCUSSION

3.1 Empirical Model Development

The empirical model developed for HDPE-Grass composite for tensile strength, proof stress, percentage elongation and flexural strength are shown in equation 4 to 7 respectively.

$$\text{Tensile Strength for HDPE} - \text{Grass Composite } (\sigma_T) = -12.5165 - 0.0478T + 0.7626M + 0.2435K + 0.0038TM - 0.0011TK - 0.0022MK - 0.0001T^2 - 0.0136M^2 + 0.0045T^2 \quad (4)$$

$$\text{Proof Stress for HDPE} - \text{Grass Composite } (\sigma_p) = 5.6394 - 0.1091T - 0.4762M + 0.0255K - 0.0066TM + 0.0142TK + 0.0203MK - 0.0002T^2 + 0.0147M^2 - 0.0513T^2 \quad (5)$$

$$\text{Percentage Elongation for HDPE} - \text{Grass Composite } (P_E) = 3.8886 - 0.0750T - 0.2447M + 0.0531K - 0.0036TM + 0.0079TK + 0.0108MK - 0.0000T^2 + 0.0077M^2 - 0.0298T^2 \quad (6)$$

$$\text{Flexural Strength for HDPE} - \text{Grass Composite } (EI) = -27.9024 - 0.0854T - 0.0385M + 1.5775K - 0.0007TM - 0.0008TK + 0.0040MK + 0.0004T^2 + 0.0073M^2 - 0.0028T^2 \quad (7)$$

Figures 1 – 4 shows the graph of effects of barrel temperature on the tensile strength, Proof stress, Percentage elongation and Flexural strength for HDPE-Grass composites both for experimental (E) and predicted (P) values respectively.

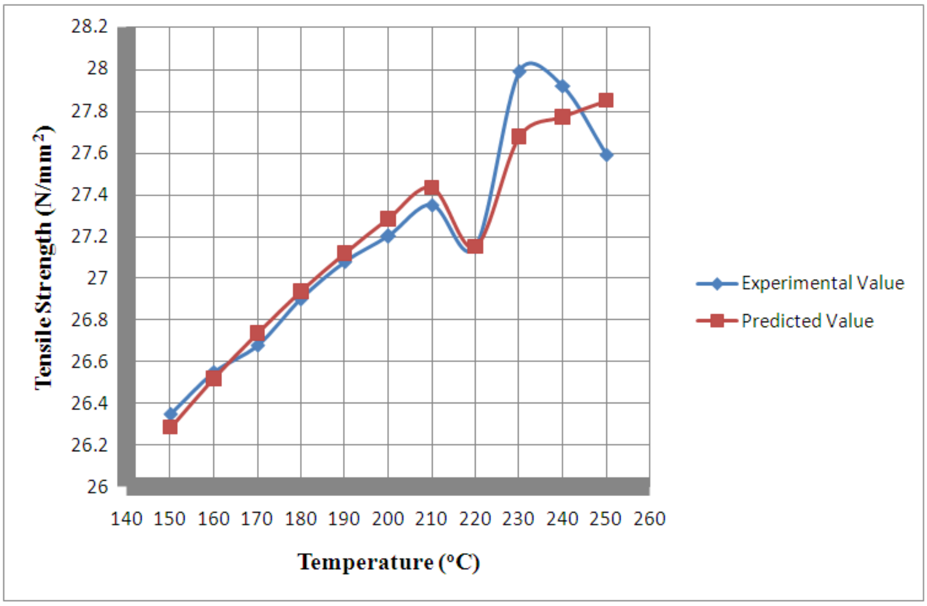

Figure 1: Graph of Effects of Barrel Temperature on Tensile Strength for HDPE-Grass Composites, Experimental (E) and Predicted (P) Values

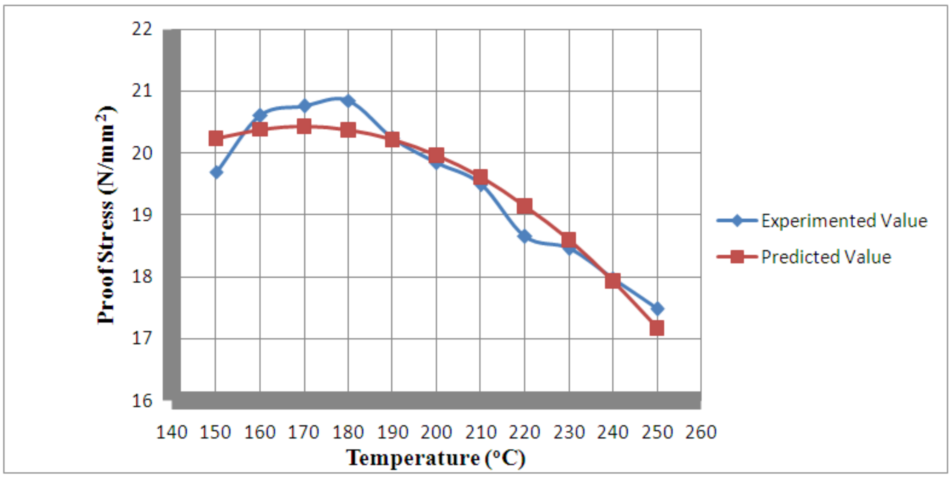

Figure 2: Graph of Effects of Barrel Temperature on Proof Stress for HDPE-Grass Composites for Experimental (E) and Predicted (P) Values

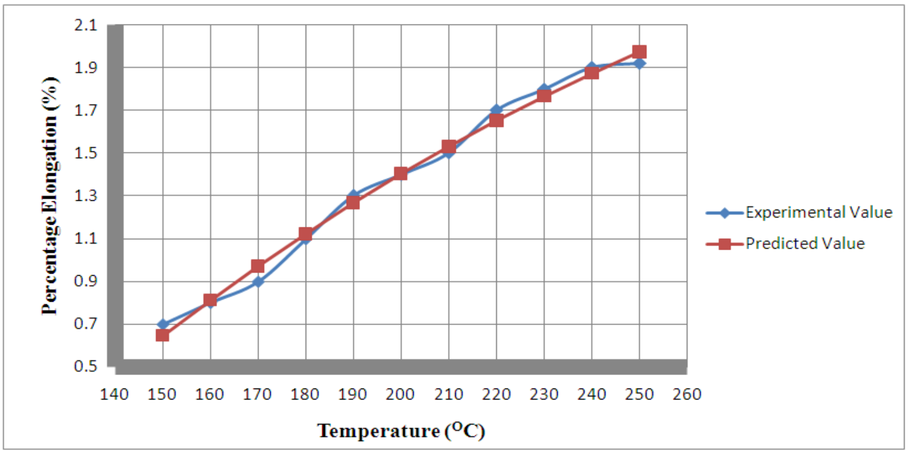

Figure 3: Graph of Effects of Barrel Temperature on Percentage Elongation for HDPE-Grass Composites, Experimental (E) and Predicted (P) Values

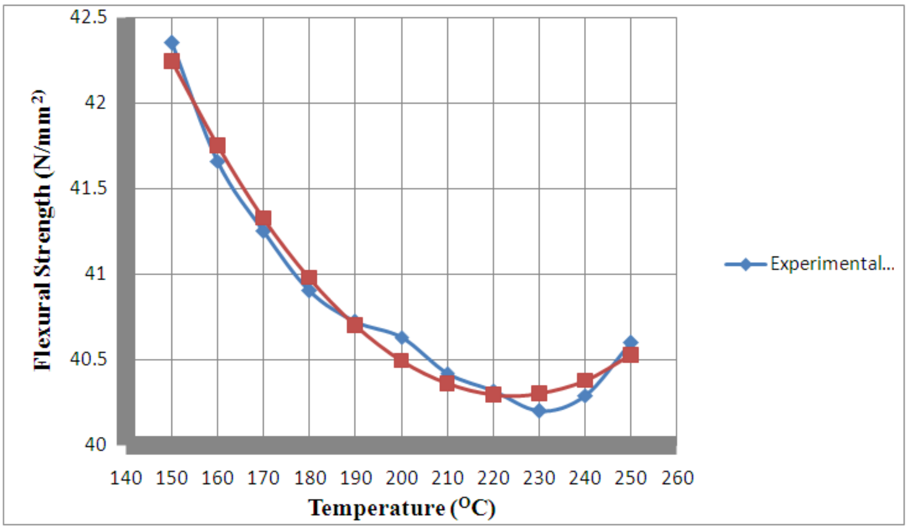

Figure 4: Graph of Effects of Barrel Temperature on Flexural Strength for HDPE-Grass Composites, Experimental (E) and Predicted (P) Values

3.2. Validation of Model for HDPE-Grass Composite

The model was validated by comparing the predicted values from empirical models with experimental data. The predicted values were found to compare favourably with measured values. The models were validated using coefficient of determination (R^2) and mean absolute percentage error (MAPE). The coefficient of determination (R^2) were determined to be 0.9243 (92.43%) for Tensile Strength, 0.9213 (92.13%) for Proof Stress, 0.9911 (99.11%) for Percentage Elongation, and 0.9821 (98.21%) for Flexural Strength respectively which indicates that a substantial good fit was achieved by the regression model developed. Moreover, the Mean absolute percentage error (MAPE) of predicted values from model when compare with the experimental values were determined to be 0.69% for Tensile Strength, 1.36% for Proof Stress, 2.98% for Percentage Elongation and 0.19% for Flexural Strength respectively. These values are significantly small and below the maximum error of 10% proposed by Liping and Deku[9]; and Osarenmwinda and Nwachukwu[3]. These values were therefore found to be satisfactory and show good predictability of the model and its adequacy.

IV. CONCLUSION

The study of the empirical modelling of injection moulded high density polyethylene-grass composite has been achieved. Empirical Models were developed for predicting the mechanical properties (Tensile Strength, Proof Stress, Percentage Elongation and Flexural Strength) for the produced composite. The models were validated using coefficient of determination (R^2) and mean absolute percentage error (MAPE). The coefficient of determination (R^2) obtained ranged from 0.9213 (92.13%) to 0.9911 (99.11%) which indicates that a substantial good fit was achieved by the regression model developed. The mean absolute percentage error of the developed models ranged from 0.12% to 6.53% which was below 10% recommended. The values obtained from the validation of these models were therefore found to be satisfactory, and shows good predictability of the model and its adequacy.

It is hopeful that the developed model will also be useful to researcher, industrialist and small scale manufacturer to ease the production of high density polyethylene-grass composite.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the assistance and contributions of the staff of Department of Production Engineering, University of Benin, Benin City toward the success of this research.

REFERENCES

[1]. Osaremwinda J. O. and Olodu D.D. (2015). Effects of Barrel Temperature on the Mechanical Properties of Injection Moulded Product. *Nigeria Journal of Technology (NIJOTECH)*, Vol. 34, No.2 pp292-296.

[2]. Chunping, D., Changing Y. and Cheng Z, (2007). Theoretical Modeling of Bonding Characteristics and Performance of Wood Composites: Part1, inter–element Contact. *Journal of Wood and Fiber Science*, vol.39, pp.48-55.

[3]. Osarenmwinda J.O, Nwachukwu J.C. (2010). Empirical Models for Estimating Properties of Developed Composite Material from Agrowaste. *International Journal of material science Research India*. Volume 7, issue 2, pp347-354.

[4]. Adeyemi, S.O. and M.B Adeyemi (2002). Curing Temperature and Hardener Resin Addition Affecting Drying and Properties of Particleboards. *Int. Journal of Materials and Product Technology*, Vol. 17, No.7, pp.590-599.

[5]. Komeil Ahmed, Mousavi Shoushtari (2017). Designing, Modeling and Manufacturing of Light Weight Carbon Nanotubes/Polymer Composite Nanofibers for Electromagnetic Interference Shielding Application. *Journal of Composites Science and Technology*. Vol. 145, pp46-54.

[6]. Osama M. E. S. K. Literature Review and Mathematical Modeling on Buckling of Laminated Composite Plates, Nile Valley University, Atbara – Sudan, November 2017

[7]. Adeyemi, S.O. and M.B Adeyemi, (2016). Temperature Effect on Extrusion Moulded Plastic. *International Journal of Materials and Product Technology*, vol. 5, No 6, pp.300-311.

[8]. Olodu, DD. (2017). Modelling and Development of Injection Moulded Plastic-Grass Composites. *PhD Thesis, Department of Production Engineering, Faculty of Engineering, University of Benin, Nigeria.*

[9]. Liping G, Deku M.S. (1992). Production of Sawdust-Plastic Composite Using Compression Moulding. *International Journal of Material Science*, vol. 2, pp. 87.

D.D Olodu and J.O Osarenmwinda. "Empirical Modelling of Injection Moulded High Density Polyethylene-Grass Composite." American Journal of Engineering Research (AJER), vol.7, no.12, 2018, pp.245-250